

TITLE: SPECIAL FLUIDS FOR USE IN A HYDROSTATIC  
TRANSMISSION

BACKGROUND OF THE INVENTION

5 Positive displacement piston pumps are well known in the art. Typically, piston pumps are comprised of a plurality of cylinders containing pistons that travel in and out of the cylinder bores. The cylinders are in fluid communication with the pump's intake or suction port as well  
10 as the pump's output or pressure port. The cylinders have mechanical valving to enable or disable the flow from either the pump's suction or pressure ports. Two types of mechanical valving are well known in positive displacement piston pumps. An example of the first type of mechanical  
15 valving is a valve plate which will enable the required timing of fluid communication as a cylinder block rotates. The second type of mechanical valving comprises check valves. In a positive displacement piston pump utilizing check valves, the check valves alternately open and close to  
20 allow fluid into and out of the piston bores, as the pistons reciprocate into and out of the cylinder bores, thus performing the pumping function.

One disadvantage of the mechanical valves used to control the flow of transmission fluid through cylinders of  
25 conventional piston pumps is that they comprise many moving parts. Typical check valves include moving poppets and springs, all of which add to the cost of the piston pump. Further, these components can degrade over time, causing inefficient pump performance or failure. As such, there is  
30 a need in the art for a positive displacement piston unit that does not rely on conventional mechanical valving,

thereby minimizing cost, improving reliability, and for other useful purposes.

Magnetorheological (MR) and electrorheological (ER) fluids have often been used in various pumping capacities, as disclosed in U.S. Pat. No. 2,651,258 to Pierce. MR fluids are those that change viscosity or even substantially solidify in the presence of a magnetic field. ER fluids behave similarly in the presence of an electric field. Because of their characteristics, MR and ER fluids have been used as transmission fluids as in Pierce, without the need for mechanical valves to control their flow. These fluids have commonly been used in brake systems as well as the active fluid in shock absorbers. To a much more limited extent, these fluids also have been used with piston pumps, as disclosed in U.S. Pat. No. 5,409,354 to Stangroom. Stangroom teaches the use of ER fluids in a mechanism triggering the opening and closing of a check valve. Stangroom does not, however, teach the use of MR and ER fluids as transmission fluids.

It is therefore a principle object of this invention is to provide cylinder valves that utilize a minimum number of moving parts and resist wear over the life of a positive displacement piston unit.

A further object of this invention is to provide a positive displacement piston unit that employs magnetorheological or electrorheological fluids to control the operation of the cylinder pistons and the hydraulic power transmission of the piston unit.

These and other objects will be apparent to those skilled in the art.

#### BRIEF SUMMARY OF THE INVENTION

The present invention consists of a positive displacement piston unit that utilizes a magnetorheological (MR) or electrorheological (ER) fluid as the transmission fluid. Each cylinder of the present invention has an intake  
5 port in fluid communication with the suction port of the pump as well as an output port connected to the pressure port of the hydraulic pump.

In one embodiment of the present invention, MR fluid is used as the active transmission fluid. Flow of the MR fluid  
10 through the cylinder is controlled by electromagnets located in close proximity to the intake and output ports of the cylinder. By energizing the electromagnet, the viscosity of the MR fluid can be increased such that the portion of the fluid immediately near the electromagnet substantially  
15 solidifies. The solidified portion of the MR fluid disables fluid through the particular passage, thereby restricting flow of the MR fluid to the cylinder.

In another embodiment of the present invention, ER fluid is used as the active transmission fluid. Flow of the  
20 ER fluid through the cylinder is controlled by electrodes located in close proximity to the intake and output ports of the cylinder. Just as with the MR fluid system, energizing the electrode can substantially solidify the portion of the ER fluid near the electrode, effectively disabling the flow  
25 of the ER fluid through the particular passage.

In either embodiment of the present invention, the MR or ER fluid serves as the transmission fluid, transmitting power hydraulically from a positive displacement piston pump to a positive displacement piston motor, or to any other  
30 device capable of using hydraulic power. Further, the characteristics of the MR or ER fluid can be used to enable or disable the flow of the transmission fluid into or out of

the cylinder. As such, the present invention does not require the use of mechanical valves to control the flow of the transmission fluid.

## 5 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective drawing of a radial piston pump of the present invention adapted for use with magnetorheological valving;

Fig. 2 is a cross sectional view of a valve adapted for use with magnetorheological transmission fluid for use in a piston pump of the present invention;

Fig. 3 is a cross sectional view of the valve of Fig. 2 together with a depiction of the magnetic field lines which are present when the valve is energized; and

Fig. 4 is a cross sectional view of a valve adapted for use with electrorheological transmission fluid for use in a piston pump of the present invention.

## DESCRIPTION OF THE INVENTION

With respect to Fig 1, a positive displacement piston unit 10 is shown adapted for use with MR transmission fluid. It should also be noted that the piston unit 10 may be a hydraulic pump or a motor. As shown in Fig. 1, the piston pump 10 may be arranged in a radial configuration.

Alternatively, the piston pump 10 may be arranged in an axial or bent axis configuration, as is common in the art.

The piston pump 10 includes a housing 12 and a drive shaft 14. A bearing 16 is eccentrically mounted on shaft 14 and includes rolling elements 18 retained within an outer race 20. Bearing 16 is an antifriction bearing such as a ball bearing or a roller bearing, and rolling elements 18 comprise ball bearings or rollers. Housing 12 includes a

plurality of bores 22. Cylinder pistons 24 fit within the bores 22 and ride against the outer race 20 of bearing 16. As the pump shaft 14 rotates, the eccentric bearing 16 gyrates about shaft 14, causing the pistons 24 to  
5 reciprocate in and out of the bores 22. This reciprocating motion of the pistons 24 draws fluid in through inlets 26, past valves 28, and into the bores 22. Fluid then leaves bores 22 through outlets 30 and past valves 32. An electronic controller (not shown) is associated with the  
10 pump shaft 14 and the valves 28 and 32, opening and closing check valves 28 and 32 as the shaft 14 rotates and drives the pistons 24 in and out of the bores 22.

Valves 28 and 32 operate in much the same manner. The valves 28 and 32 may be adapted for use with MR fluid, as  
15 shown in Fig. 2. Valve 28 includes a channel 34 formed between an electromagnet 36 and the housing 12. Channel 34 is in fluid communication with the bore inlet 26 and a valve outlet 38. A solenoid coil 40 encircles electromagnet 36 and is operatively connected to an electronic controller  
20 (not shown) via wires 42. The electromagnet 36 and solenoid coil 40 serves as the electro-energized field generating element, which creates a magnetic field 44 as described hereafter. It should be noted that the term "electro-energized field generating element" is a generic term that  
25 refers to both magnetic and electric fields.

When the solenoid coil 40 is energized by the controller, a magnetic field 44 is created, as shown in Fig. 3. The magnetic field 44 is concentrated across the channel 34, causing the MR fluid within the channel 34 to  
30 substantially solidify. As the MR fluid solidifies, MR fluid within the bore inlet 26 cannot move through the channel 34 and into the bore 22. In essence, the presence

of the magnetic field 44 works to close off the valve 28, preventing the MR fluid from flowing out of valve outlet 38. When the solenoid coil 40 is de-energized, the magnetic field 44 dissipates, allowing the MR fluid to again flow  
5 through channel 34 and past outlet 38.

Alternatively, the valves 28 and 32 may be adapted for use with ER fluid, as shown in Fig. 4. In this configuration, an electrode 46 is used as the electro-energized field generating element in place of the solenoid  
10 coil 40. The electrode 46 is mounted on an insulation strip 48 and connected to an electronic controller (not shown) via wire 42. When the electrode is energized, an electric field (not shown) is concentrated across the channel 34, causing the ER fluid within the channel 34 to substantially  
15 solidify. As the ER fluid solidifies, ER fluid within the bore inlet 26 cannot move through the channel 34 and into the bore 22. In essence, the presence of the electric field works to close off the valve 28, preventing the ER fluid from flowing out of valve outlet 38. When the electrode 46  
20 is de-energized, the electric field dissipates, allowing the ER fluid to again flow through channel 34 and past outlet 38.

In operation, the drive shaft 14 rotates, causing the eccentric bearing 16 to gyrate and drive the pistons 24 in  
25 and out of the bores 22. As the piston 24 moves out of the bore 22, an electronic controller (not shown) de-energizes valve 28 such that the rheological transmission fluid may pass through inlet 26 and into the bore 22. At the same time, the electronic controller energizes valve 32 such that  
30 the rheological transmission fluid does not pass through the outlet 30. As the piston 24 moves into the bore 22, the electronic controller de-energizes valve 32, allowing the

rheological transmission fluid to pass through the outlet  
30. At the same time, the electronic controller energizes  
valve 28, thereby preventing flow of the rheological fluid  
from the inlet 26 past valve 28. In a piston unit 10  
5 adapted for use with magnetorheological transmission fluid,  
valves 28 and 32 are equipped with solenoid coils 40 to  
produce a magnetic field 44 that substantially solidifies  
the MR fluid. Alternatively, in a piston unit 10 adapted  
for use with electrorheological transmission fluid, valves  
10 28 and 32 are equipped with electrodes 46 to produce an  
electric field that substantially solidifies the ER fluid.

Those skilled in the art will appreciate that the same  
unit can be used as either a hydraulic pump or as a  
hydraulic motor by simply applying voltage to the valving at  
15 the desired times during shaft rotation.

Those skilled in the art also will appreciate that the  
unit of the present invention can be used as a variable  
displacement pump in at least two ways. First, the  
electronic controller can selectively refrain from enabling  
20 the outlet flow from some portion of the pistons. By not  
enabling the unit to pump with all pistons, or by not  
allowing the unit to motor with all pistons, the fluid from  
the selected pistons will not be pumped or motored and the  
piston unit's displacement will be reduced. Second, it is  
25 also possible to energize an inlet valve and de-energize an  
outlet valve at a variable point in time as a piston travels  
back into its bore. In this manner, a portion of the  
displacement of the piston will serve to push fluid back  
into the inlet passage rather than through the outlet  
30 passage. At the desired point during piston travel, the  
valve states will be switched and the remaining portion of

the stroke will displace fluid to the outlet port. In this manner, flow is also reduced.

It is therefore seen that by the use of a rheological transmission fluid to control the communication of fluid  
5 into and out of cylinder bores, this invention permits the efficient operation of a positive displacement piston unit without the need for mechanical valving.